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Conceptions and Models of Secondary Students Learning Superconductivity

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Abstract

A research based educational path on superconductivity was designed for high school level. Students explore diamagnetic and electrical properties of superconductors, recognizing the role of electromagnetic induction and the inherent correlation of these properties in the Meissner effect. Feasibility tests with over 300 students were conducted in different Italian contexts. A research experimentation implemented in a 13 grade high school class composed by 16 students was focused on learning patterns of students, monitored with tutorials and pre/post test. It emerged as they use the magnetic field lines to describe the phenomenology of superconductors passing from the idea that a superconductor is transparent to an external magnetic field, the construction of coherent model based on the role of the induced persistent currents

1. Introduction

Superconductivity constitutes an important phenomenology of the twentieth-century physics [1-2], that can be modelized in different interpretive frames [3] and also proposed at school level. It is perceived by students as interesting because, it triggers their need to understand the process of the creation of the superconductive state and stimulates the production of interpretative models [2]. It also activates a critical reanalysis of their knowledge on electromagnetism [4], connections between science and technology related for example to the maglev trains and the supermagnets used in medical diagnostic tests, meaningful connections between classical and quantum physics [2,5]. Within the framework of European projects MOSEM 1-2 [6-8], kits of educational experiments have been developed, and educational paths have been designed on a phenomenological exploration of superconductivity in secondary school [7-9], integrated in the electromagnetism curricula [10-12]. From 2010 research experimentations were conducted in eight Italian contexts with 393 students of different schools. These experimentations constituted positive feasibility tests on the possibility of introducing superconductivity in high school. They also documented the systematic interest of the students, which was not limited to the simple observation of phenomena unusual and surprising, but mostly focused on the exploration of interpretative hypotheses. They showed that the personal involvement, in the exploration of the collection of problem/situations offered to students, activates planning aimed to test hypotheses based on the attribution to superconductors of ordinary electrical and magnetic properties, which are gradually changed recognizing the nature of ideal conductors and diamagnets [11-12].
To go deeper in the analysis of the students learning processes and their models, a research experimentation has been implemented in last year class of an Italian upper secondary. Here, it will be discussed what role students attribute to the electromagnetic induction process in the Meissner effect.

2. The research questions

The present work aims to give answers to the following research questions:.
RQ1. Can the phenomenological exploration of superconductivity levitation produce a better understanding of the phenomena and also of the electromagnetic processes?
RQ2. Such spontaneous models students' active in the (real/concrete) analysis of ideal cases?
RQ3. How these models are modified by the phenomenological exploration and which role plays the representation of vector field lines and of the magnetization vector in these models?

3. Instruments and methods

The experimentation was carried out in a 13 grade class of a Scientific Lyceum of Udine, composed of 16 students (18-19 years). The educational path implemented in the experimentation was based on the proposal developed within the projects Mosem 1-2 and using the explorative didactic kits developed in these projects [6-9], giving as conceptual references the field lines and the magnetization vector. It was implemented proposing to students a phenomenological exploration [11-12], activated by stimulus worksheets based on a strategy Inquiry-Base Learning (IBL), in 12 hours. The same questionnaire was used as a pre-test and post-test, The educational path tooks over what was done by the hosting teacher concerning the analysis of magnetic interactions, magnetic field and flow, magnetic properties of matter, and integrating the superconductivity into the curriculum planned by the teacher. It will be presented in section 4. The students had followed a three-year undergraduate studies in physics (3 hours per week) based on lectures, without laboratory. Based on the initial assessment of the teacher, on the basis of standard criteria [13], the class was mid-level, with three students with low profit due to limited work and interest.

The present paper considers only data from the students open answers to four questions of the pretest-posttest (questions Q9-Q10 and Q11-Q12), presented in Section 5. Open-ended responses were analyzed using the criteria of qualitative research [14], identifying the categories of responses and/or iconic representation in particular distinguishing between interpretive models and descriptive/phenomelogical models and typical naive responses. The frequencies of these categories were then evaluated for the entire sample by comparing the distributions of answers given in the Pre-Post using the Yates $\chi 2$ test. Particularly the focus was to highlight the changes in the ways of discussing and distinguishing the cases involving conductor with $R \neq 0$ and superconductor with $R = 0$.

4. The knots explored in the educational path

The educational path followed with students regards the following main knots (S1-S11):

S1) Interaction of a magnet with various objects (identification of ferromagnetic ones, of the dipolar nature of the magnetic field sources) and construction of the magnetic field lines representation;

S2) Interaction of a high magnetization neodymium magnet and non-ferromagnetic objects hanging or placed at the end of a suspended yoke, to identify para/diamagnetic properties of materials.

S3) Ørsted Experiment and magnetic field generated by currents of different geometry.

S4) Electromagnetic induction with on-line sensors and the law of Faraday-Neumann-Lenz.

S5) Role of eddy current when a magnet falls into/on a conductor.

S6) Analysis of the interaction of a disc of YBCO and a magnet at T_o, to explore its magnetic properties, and the interaction of a magnet and a ferromagnetic ring, interposing a disc of YBCO, to recognize that the magnetic field can penetrate in the YBCO at T_o.

S7) Analysis of similar situations with the disc of YBCO al T_{LN}, to recognize that the interaction is always repulsive, from which emerges the diamagnetic nature of the YBCO disc.

S8) Exploration of the stability of levitation for short elongations, evidencing adaptation and feedback.

S9) Role of electromagnetic induction in the levitation of a magnet on a superconductor.

S10) Measure with on-line sensors of the breakdown of the electrical resistivity of an YBCO disc [15].

S11) Characterization of the properties of a superconductor (Meissner effect- $R = 0$, $B = 0$).

5. The questions of the Pre-Post Test

The questionnaire designed and used as pre-test and post-test was composed of a total of 13-problem situations, of which at least two related to the same knot of the path. In the following of this section, the four questions here considered will be presented.

The structure of each question is of the following type, with appropriate modifications and adaptations: presentation of the situation, often adding to the description an illustration; prevision on the phenomenon that can be expected to happen, or representation of the situations that could be realized, request to represent the illustrations proposals or those of their own sketched the field lines and the magnetic dipole vectors; comparison of similar situations involving materials with electrical and magnetic properties and ordinary superconductors.

The entire questionnaire was opened with the introduction of the un-usual representation of the magnetization vector, offered as instruments of representation of magnets or other systems evidencing magnetic properties.

Question Q9 .The question Q9, divided into four questions, regards the first situation in which a magnet is made to fall over a thick copper plate and the similar situation of a magnet that "falls" above a superconductor and from it is repelled due to Meissner, situation explored by students in the laboratory. “A disc magnet, such as that shown in the fig.1, is made to fall on top of a thick copper plate. 9.1 The falling motion of the magnet will be influenced by the presence of the copper plate? 9.2. Represent in the figure the magnetic dipole moments that may be present in the two systems; 9.3. It is

possible that for some appropriate geometry of the copper plate and the magnet, i.e. to a suitable magnet can achieve the situation where the magnet stops and remains suspended above the layer? 9.4. Something would change if instead of the copper plate places itself on a zero resistance layer?"
Question Q10. Concerning the situation related to fig 1 (right) the question posed were; 10.1 How can you explain this phenomenon? 10.2.Would it change anything if the conductor had zero resistance?

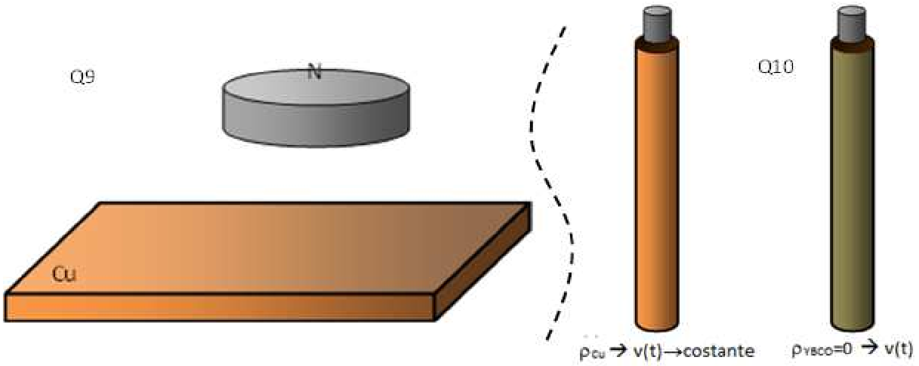


Fig.1 Situations proposals in questions 9 and 10 of post-test: Q9 a magnet falling over to a copper plate; Q10: a magnet that falls within a copper tube, a tube superconductor.

Question Q11-12. The question Q11 and Q12 request to represent how the field lines of an external homogenous magnetic field are affected by the presence of a ferro/para/dia-magnetic cylinder and a cylinder with zero electric resistance. The magnetization vector representation is also request.

6. Data Analysis.

Question Q9.1 In the pretest the majority of the 15 responding students to question Q9.1 indicated that the fall of the magnet is influenced by the presence of the copper plate, "but only very little, because the Cu is diamagnetic" (13/16). One student predicted that "Copper is a good conductor and the magnet attracts" and another that the magnet "Yes, it is slowed down by the plate and the magnet is very little and weighs just then Fp is very small and will fluctuate"
In the post test, most of the students stated that the magnet "Slowed due to the currents induced" or who have "induced currents that repel the magnet" (10/16). A small group limited the answer to a description of the phenomenon "Yes is affected because there is a slight resistance. In the fall we also notice a certain repulsion "(4/16). Two students indicate the plate influence the fall of the magnet, but "not so significant, since copper is a diamagnetic substance"(2/16).
Fig.2a shows the distribution of responses in the pre-test and post-test respectively, different with a confidence level greater than 99.5%.(χ^2=21,87>16,75 , P<0.005; χ^2(Yates)=44,6>16,5, P<0.005).

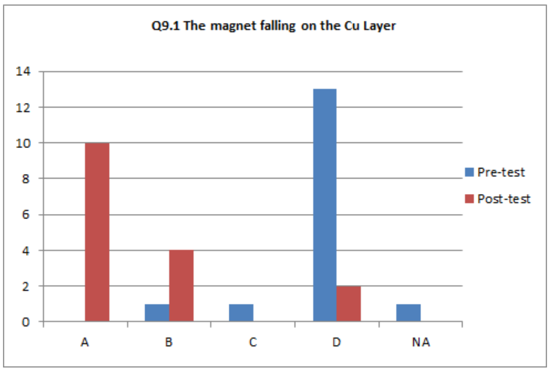


Fig. 2a. Distribution of categories of answers to question Q9.1: A) "Slowed down motion because of the induced current"; "induced currents that repeal the magnet"; B- "muffled motion"; C – "Cu have low resistivity then it attracts the magnet more fast"; D – "Yes, bust just very few, because Cu is diamagnetic"; NA – No answer

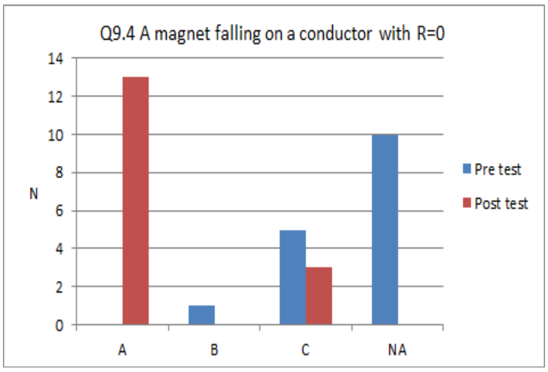


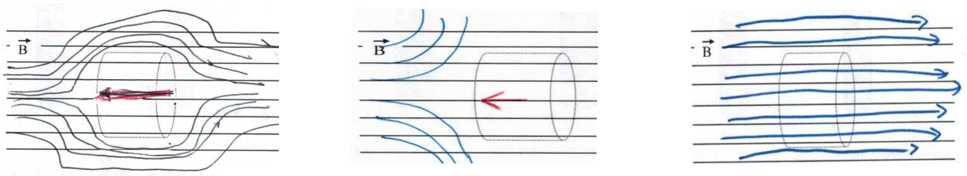
Fig. 2b. Distribution of categories of answers to question Q9.4: A: would remain suspended / levitating (in 4 cases: perfect diamagnet); B: The phenomena of repulsion would be stronger; C: Yes, why he does not repel the magnet so that would not diminish its speed; NA: no answer

A marked change has occurred also in question 9.4 (fig 2b), which asks if something would change in the event of the fall of the magnet of an ideal conductor. Only six students answered in the pre-test providing that “Yes [change], because it do not repel the magnet so its speed di not decrease" and in one case that "The phenomenon of repulsion would be stronger." In the post test the main category is the one that indicates that the magnet "would remain suspended", "would levitate," adding in 4 cases, because the system is a "perfect diamagnet" In three cases remains the idea that a perfect conductor has no influence on the fall. The distributions in the pre-test and post-test are significantly different (χ^2=24,5>14,86 , P<0.005; χ^2_{Yates}=56,5>14,86 , P<0.005)

The answers included in the category C) underlying the idea that zero electrical resistance means that "the system offers a no-resistance to the fall of the magnet." This also implies that a system with zero electrical resistance would be essentially completely transparent to an external magnetic field.

Question Q12. Concerning the case of a zero resistance cylinder placed in the uniform magnetic field the categories of representation are illustrated in Fig.3 with relative distributions of frequencies.

In the pretest, the question has been largely ignored by the students and the only model that has emerged is related to the category C which clearly explains the concept that a conductor with zero resistance is transparent to an external magnetic field, already discussed in relation to the above questions: "Do not since there resistance field lines remain unchanged. "



A) Meissner B) repelled lines C) unchanged lines

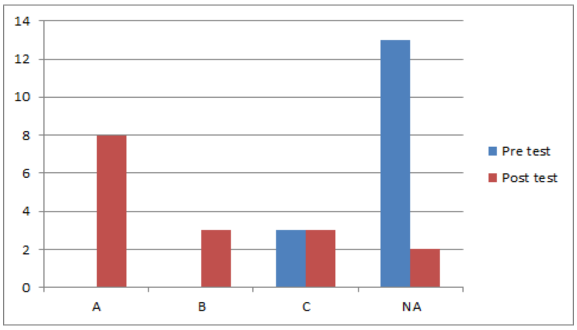


Figure 3. Representations of the magnetic field lines and the induced magnetic dipole moments in the case where a superconducting cylinder is inserted into a uniform magnetic field and relative frequencies with which they emerged in the pre-test and in the post-test.

In the post-test prevails category A which provides field lines outside the superconductor and a magnetic dipole moment in a direction opposite to that of the external magnetic field: "The cylinder behaves like a" perfect diamagnet ", shielding the lines of the external field, so that on the inside you have zero magnetic field. "The model showed further characterizes the Meissner effect through the action of external magnetic field on the superconducting or on the field lines, objectualized as concrete physical entities: "For the effect meissner the cylinder Sc assumes the ability to" diamagnet perfect "rejecting the B-field. "This representation is obviously triggered by similar expressions often present in the texts and popular works, both school and university on superconductivity.

The two distributions differ statistically with a degree of significance of 99.55 (χ^2=19,07>14,86 , P<0.005; χ^2(Yates)=50>14,87 , P<0.005*).* In 6/16 cases the correlation emerges between the answers of type A) and the representation of the field lines and the vector of magnetic dipole in relation to the ordinary magnetic systems. The path explored in the classroom has enabled systematic changes, as can be seen in the answers given by the students in the pre-test and post-test, and conceptual structures with a degree of consistency shown by the correlations in students answers.

7. Conclusions

Within the framework of European projects MOSEM1-2, educational kits were developed and an educational path was designed, for a phenomenological exploration of superconductivity in secondary school. To investigate how students face and modelize the phenomenology of superconduction, a research experimentation was conducted in a 13 grade class composed by 16 students. The activities carried out by the students consisted of 10 hours activated and monitored with stimulus type IBL worksheets and 2 hours for the pre/post-test. Here, were analyzed data from four questions of the pre/post-test concerning the electromagnetic induction in the Meissner levitation.

In the analysis of situations where a magnet falls on/inside a copper conductor, a great change has been observed in student conceptions: from naive ideas (often centered on the properties of the diamagnetic Cu and on a negligible interaction magnet-copper) to the recognition of the role of the variation in time of the magnetic flux and to the strong interaction (RQ1). This has enabled at least 2/3 of the sample also consistent modeling of levitation Meissner, triggered by an inductive process and supported by the absence of dissipative effects. The comparison of what happens in the same situation with a conductor with zero resistance, the majority of students have passed from the idea that a conductor with zero resistance does not affect at all the fall of the magnet, to models based on a strong repulsive interaction due to induced permanent currents, the diamagnetic properties of the superconductor, the absence of the Joule effect. (RQ2)

In the representation of the field outside and inside the systems composed by different materials, students in all cases have improved their competence in tracing field lines and magnetization vector, in the case of ordinary systems. The representations of the field around and inside of a SC are at the end of the educational path in agreement with $B_{inside}= 0$ (70%), being the students models before the experimentation based on the idea that a SC does not influence the external field (model emerged already in the initial exploration of objects para / diamagnetic as transparent objects in B). The models are modified through the exploration phenomenological, in most cases producing a vision of superconductors as systems characterized with $B_{inside}= 0$ and $R = 0$, when it is developed a conceptual network coherent activated by the correlation of different phenomena. A local view of phenomenology does not activate this understanding. (RQ3).

The developed models focus on specific aspects important in the phenomenology observed in the second of what has attracted the attention in particular, the processes of electromagnetic induction, the Joule effect. Modeling activity that integrates phenomenological exploration may be important to enable a comprehensive and complete process.

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